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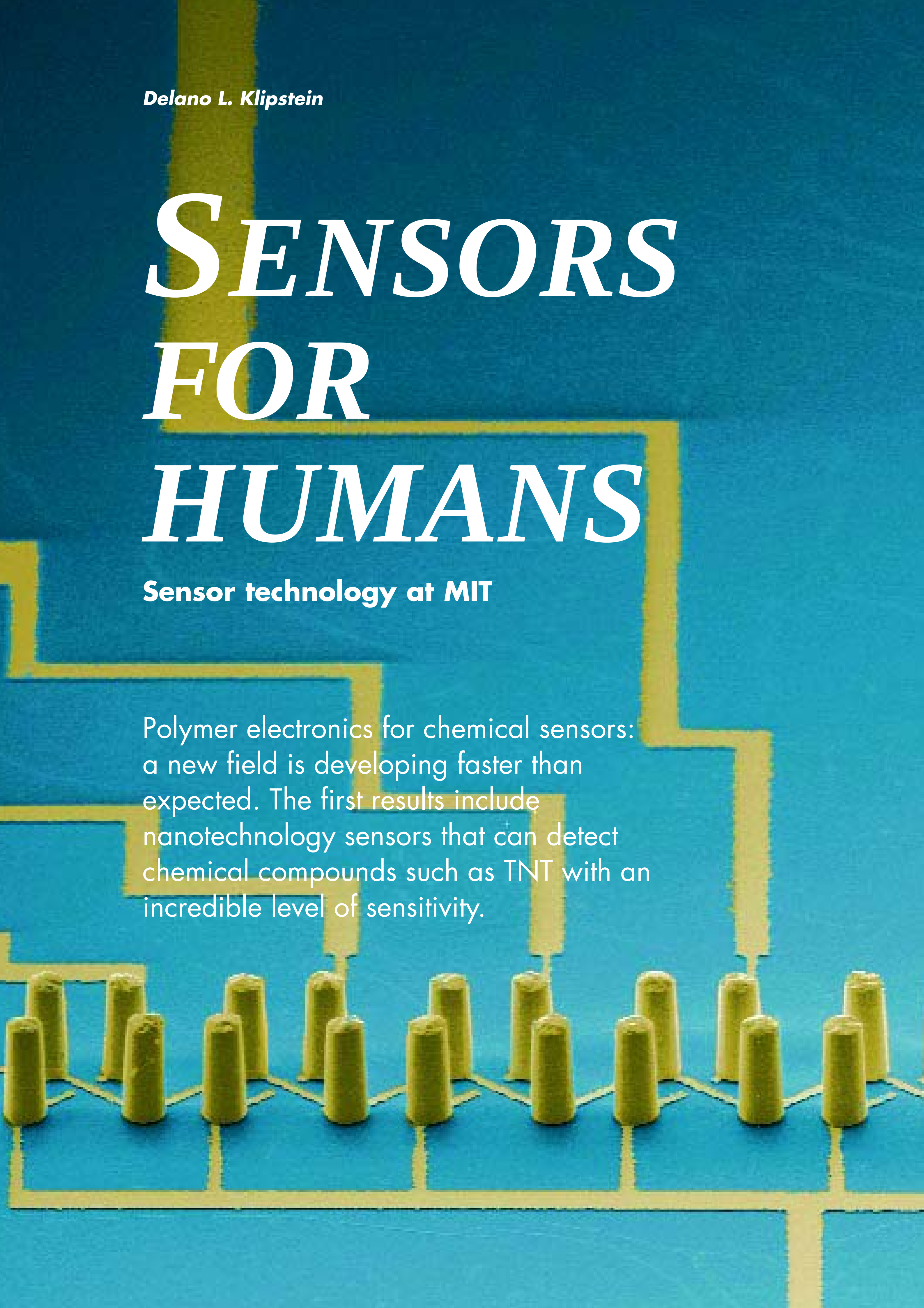
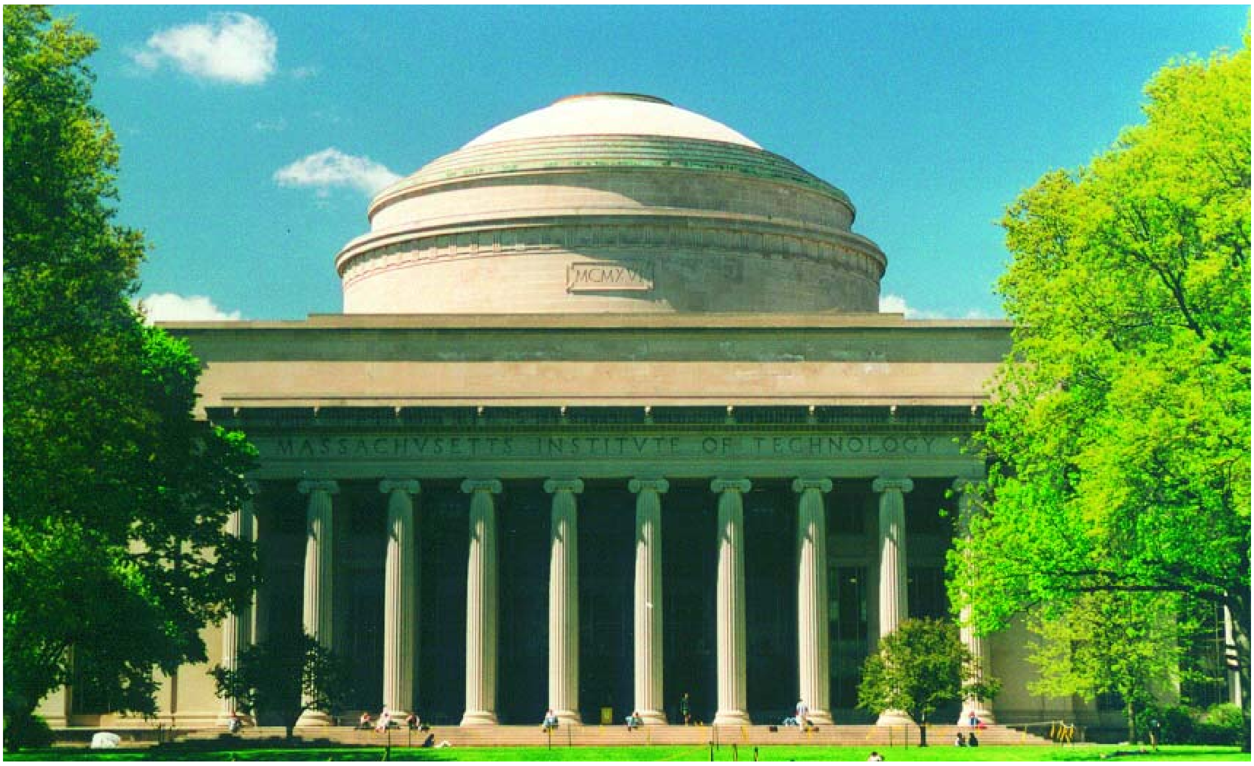
SENSORS FOR HUMANS

Sensor technology at MIT

Polymer electronics for chemical sensors: a new field is developing faster than expected. The first results include nanotechnology sensors that can detect chemical compounds such as TNT with an incredible level of sensitivity.





The 'hallowed halls' of the Massachusetts Institute of Technology. (Image: D.L. Klipstein)

'Polymer Electronics for Chemical Sensors' was the topic for the tenth research and development conference at the Massachusetts Institute of Technology (MIT), which gave an overview of current developments in the field of plastic electronics. The name of one speaker made us prick up our ears: Professor Timothy M. Swager is associate director of the 'Institute for Soldier Nanotechnologies' at MIT. What was he seeking to achieve?

The MIT professor came straight to the point, summing it up in one sentence: "We want to build sensors so small that they could in principle be constructed from a single molecule". An ambitious target, and certainly not one that can be achieved in the foreseeable future. Or can it? Some substances, such as nitric oxide (NO) are relatively simple to detect using polymer sensors. NO is a colourless, poisonous gas which increases the conductivity of certain polymers. With a good sensor it is already possible to detect as little as a few nanograms. Using more sophisticated polymer systems, more complex mixtures of substances can be detected.

Swager and his colleagues have, as an example, developed a prototype of a detector which can respond to as little as 10^{-6} grams of TNT explosive. With that a very sensitive land mine detector could be built. What interests potential users more at the moment, though, is the possibility of dramatically improving the sensitivity of baggage monitors at airports. In a commercial product such a detector could be more than ten thousand times more sensitive than those currently used. And the chances of being able to smuggle explosive on board an aeroplane in the heel of one's shoe would fall to zero at a stroke.

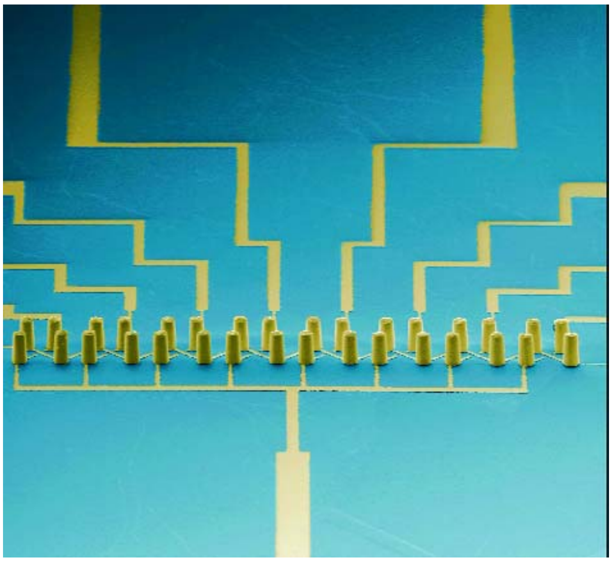
At MIT they are well aware that a lot of development work lies ahead. At the moment it is only possible to make polymer sensors in the shape of a one-dimensional strip, whereas effective chemical sensors need to have a three-dimensional structure. Two-dimensional planar sensor structures will have to be made before we can even consider going into the third dimension.

Chemistry is being brought to bear on electronics in other areas too. Swager and his colleagues have developed a tiny laser made from a polymer, capable of delivering an output power of up to 75 nW. A ring laser has also been built using microstructures made from dinitrobenzene. Using cunning molecular design techniques signal gains of up to 10^5 have been achieved. The MIT professor is absolutely certain that new results in chemistry will have a dramatic impact on the future of electronics.

Wireless physiological data measurements

Phil Shaltis, research assistant in the Department of Mechanical Engineering, agrees. He reported a sensor in the form of a finger ring which can measure blood pressure and oxygen saturation levels and transmit them wirelessly to a monitoring station.

The challenge in this case is not the instrumentation technology itself, but the problem of minimising power consumption. The data are measured on an artery in the finger. The ring itself was designed using finite element methods to guarantee reliable operation: it must not press too hard against the bones in the finger, or errors will be introduced into the readings,



Microscopically small grids form a cell trap. This allows individual cells to be observed and moved using electrical impulses. (Image: Voldman/MIT)

ultimately giving rise to incorrect measurements of blood pressure; but on the other hand, the better the ring fits, the better the signal-to-noise ratio achieved. Pressure is therefore only applied locally on the finger in the spots where the artery in question lies. The pressure itself is measured using infrared sensors.

What can we do with a sensor like this in everyday life? This is being researched at the Massachusetts General Hospital (MGH) in Boston, located opposite MIT on the other bank of the Charles River. Similar measurement devices for these kinds of data are already used in hospitals, and although they are very advanced they are also comparatively large: the ring developed at MIT is a thousand times smaller. At present it is used in parallel with traditional instruments, including at a stress EKG unit. Early results are already available: identical measurements are obtained from patients at rest, while under stress the ring sensor gives much more accurate readings and, most importantly, fewer artefacts.

Figure 3. Professor Timothy M. Swager: "We want to build sensors so small that they could be constructed from a single molecule". (Image: private)

Many different approaches were taken in trying to minimise the power consumption of the ring. A high modulation rate is used during data transmission to keep the transmit time as short as possible. A 'sleep mode' for the ring saves yet more power: there is no need to take measurements continuously. For special applications like this one a dual-architecture processor has been developed at MIT which meets the extreme performance requirements better than conventional processors. The device also has an interesting market in the area of fitness. Once the system has proved itself in hospitals, the next project is to create a monitoring system for intensive training.

Other experiments are being carried out to record stress situations while driving. There is a close relationship between brain function and cardiac activity. Stress, anger and physical tiredness are reflected in an increased heart rate. For example, a system which provided continuous medical monitoring of the driver of a long-distance coach could increase safety.

As well as this sensor ring, active sensors have been placed in cuffs to be worn on the arm: so-called 'wearable cuffs'. Many people require continuous monitoring of the most important body functions in order to be able to call for help quickly in case of an emergency. Another approach to monitoring such patients is to use 'smart shirts', which connect together a whole network of body sensors. At present they require too much wiring to be used inconspicuously: development work is in progress to reduce the number of connections to just two (for the power supply). The power supply wires can be used simultaneously for signal transmission, forming a bus system for the data to be communicated. Such unprotected bus systems are susceptible to interference, in particular to the inevitable noise. An initial analysis of the noise spectrum indicates that this idea is practical over a wide range of frequencies, certainly above 100 kHz.

MEMS for biosensors

Joel Voldman, Assistant Professor of Electrical Engineering at MIT, reported on BioMEMS. Cells contain a large quantity of useful pieces of information which are not only of interest to doctors. Modern criminology is also dependent on cell research. Today's typical experiments use cell cultures consisting of more than a million individual cells. The cells' environment is poor: the cells die during the experiments, which changes the nature of the culture. What are wanted are biosensors which can extract the same information, and possibly much more, from just a few cells. MEMS (micro-electromechanical sensors) look as if they might make suitable biosensors.

Using such microminiaturised experimental methods it is possible to aim for better results. For example, micromanipulation of samples can help extract desired information. The problem with experimenting on single cells lies in optical screening: one can only study what one can screen for, and one can only screen for what one can see. The classical microscope always shows the same section. If the sample being studied is on a glass slide, then there is no difficulty. However, when using dynamic screening, the cell material being studied flows across the screen, and thus there is always the danger that an interesting part of the sample might be lost for ever.

Voldman and his colleagues are looking for a solution between these two extremes of dynamic and static screening, where there might be the possibility of repeating an observation to obtain reliable data. Using MEMS one individual cell can be studied. The cells are kept alive in a transparent nutrient fluid. They can be studied using optical and electrical techniques, as well as by using ultrasound. Using microscopically small grids cell traps can be constructed in which cells can not only be observed, but can also be moved around using electrical impulses.

Using these technologies we hope to gain insight into a secret that also concerns quantum physicists. Today we know very little about what influence observation from outside has on a cell. As in quantum computing, we have to be wary of the problem that when reading or writing information one always runs the risk of distorting the information itself.

(040040-1)

Figure 4. Professor Joel Voldman: "We are looking for experimental methods that allow us to observe individual cells"'. (Image: private)

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